Development of an Innovative Alternative to Hydrogen-Powered Engines for Unmanned Aerial Vehicles

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ABSTRACT

New energy sources such as solar energy and hydrogen energy have been applied to the Unmanned Aerial Vehicle (UAV), which could be formed as the hybrid power sources due to the requirement of miniaturization, lightweight, and environmental protection issue for UAV. Unmanned Aerial Vehicle (UAV) hydrogen-powered technology is significantly related to the flight performance of UAVs, which has become one of the most important development directions of aviation. This article presents and discusses the classification, working principles, characteristics, and critical technologies of fuel cells. Additionally, future technologies and development, including the high-power density motors, converters, and power supplies are discussed for hydrogen-powered engines of UAVs.

Keywords: UAV (Unmanned Aerial Vehicle), hydrogen powered engine, energy management strategy, engines, power supply, fuel cells

I.Introduction

Unmanned Aerial Vehicles (UAVs) are aircraft that are guided autonomously, by remote control, or by both means and that carry some combination of sensors, electronic receivers and transmitters, and offensive ordnance. They are used for strategic and operational reconnaissance and for battlefield surveillance, and they can also intervene on the battlefield – either indirectly, by designating targets for precision-guided munitions dropped or fired from manned systems, or directly, by dropping or firing these munitions themselves.

UAVs encouraged by recent technological developments, have seen a dramatic interest boost in recent years and are already considered as an integral and indispensable part of modern armed forces[1] with an increasing number of dual use and civil applications[2]. Most developed countries have already acquired UAVs or plan to do so soon. Current propulsion systems are based on different types of internal combustion engines fed by fossil fuels, but with the global energy situation, preceded by the energy crises of the 70s and strategic incentives to make alternative propulsion systems, fuel cells have started to be introduced. These have advantages in terms of endurance, efficiency, emissions, and stealth which make them ideal

[1]S. Wezeman, "UAVs and UCAVs: Developments in the European Union.

[2] L.G. Freire Bouillon,Perfiles IDS: Sistemas A´ereos no Tripulados (UAS), IDS, Madrid, Spain, 2009.;D. Maple,M. G. S´anchez Jim´enez, J. M. Sanjurjo Jul, and C. Calvo Gonz´alez-Regueral, Perfiles IDS: Sistemas no Tripulados, IDS, Madrid, Spain, 2012.

for UAV applications[3] . Starting from the premise that important energy and environmental problems in our society exist, the advantages and disadvantages of fuel cells as an alternative for UAV propulsion systems are going to be analyzed. Fossil fuels pose a serious environmental and economic problem. They are the main cause for the increase of CO_2 presence in the atmosphere, declared to be one of the most important culprits of global warming and the atmospheric emissions of other pollutants[4]. The current economic and financial crisis has been aggravated by the high energy prices[5]. Of course, the world of aviation is not an exception to the above considerations. UAVs are in their nascent stage of development (in fact, their regulations are in process of being written), although the implementation of fuel cell propulsion systems is more advanced than in conventional aircrafts. The main reason is the fact that UAVs are unmanned, thus, weighting comparatively less and not needing the life support systems for the crew and passengers, making them ideal for this new technology. Also, fuel cells are still too heavy to propel any large aircraft; they have a lower power density when compared with conventional turbines[6] . In a military setting, there are other key operational advantages such as stealth and a lower thermal signature

II. Methods And Results

Compared with the unmanned aerial vehicle powered by an Internal Combustion Engine (ICE) which uses fossil fuel, the UAV driven by an electrical motor, which uses new energy sources, takes many advantages in terms of emission, efficiency, stealth and noise[7]. For small rotor UAVs, only a suitable battery pack can meet all power requirements and support a flight mission of tens of minutes, and a series of civilian small UAVs have been successfully launched by some famous manufactures such as DJI-Innovations (China), 3D Robotics (USA) and Parrot (French). However, considering longer endurance and higher flight speed, solar cells and fuel cells, which have higher energy density, are used as main propulsion energy in UAV. Solar cells, in which power's performance is significantly influenced by temperature and sunlight, are usually used in high-altitude UAV with Maximum Power Point Tracking (MPPT) control[8]. The UAV powered by a solar cell has light weight but more larger size and aspect ratio with the limitation of wind loading and aeroelasticity. On the other hand, in lower altitude and lower speed situation, fuel cells have more applications. This article is more concerned with the hybrid power system based on fuel cells. The first documented fuel cell UAV flight was the Hornet UAV from Aero Vironment in 2003, with a wingspan of only 38 cm and a profile of 0.25 h[9]. In 2006, Georgia Tech University built a UAV powered by a 500 W fuel cell[10]. It was one of the first projects undertaken by a university to study the benefits and suitability of fuel cells for UAV. In 2013, the Office of Naval Research (ONR) achieved a world record endurance with its fuel cell powered UAV-Ion Tiger, with flight duration of 48 h[11]. In 2017, an innovative

[3] M. F. Hordeski,Hydrogen&Fuel Cells: Advances in Transportation and Power,The Fairmont Press, Lilburn, Ga, USA, 2009.

[4] Intergovernmental Panel on Climate Change (IPCC), Climate Change 2007: Synthesis Report, IPCC, Geneva, Switzerland, 2013, http://www.ipcc.ch/publications and data/publications ipcc fourth assessment report synthesis report.htm.

[5] U.S. Department of Energy, Transportation Energy Data Book, 2010, http://cta.ornl.gov/data/index.shtml.

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[7] Liu L, Du MY, Zhang XH, Zhang C, Xu GT, Wang ZP. Conceptual design and energy management strategy for UAV with hybrid solar and hydrogen energy. Acta Aeronaut Astronaut Sin 2016;37(1):144–62 [Chinese].

[8] Barbosa R, Escobar B, Sanchez VM, Hernandez J, Acosta R, Verde Y. Sizing of a solar/hydrogen system for high altitude long endurance aircrafts. Int J Hydrogen Energy 2014;39 (29):16637–45.; Abbe G, Smith H. Technological development trends in solar-powered aircraft systems. Renew Sustain Energy Rev 2016;60:770–83.

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[10] Bradley TH, Moffitt BA, Thomas RW. Test results for a fuel cellpowered demonstration aircraft. J Press Vessel Technol ASME 2006;119(2):185–91.

[11] None. NRL Ion Tiger fuel cell UAV extends flight endurance record. Fuel Cells Bull 2010(1):4.

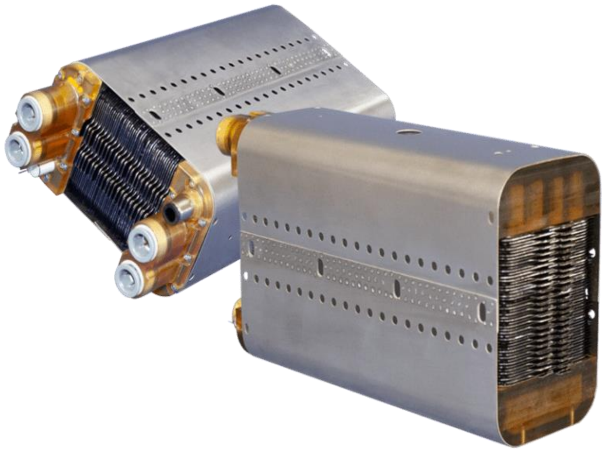
tilting-rotor UAV based on fuel cells from the Korea Aerospace Research Institute (KARI) was exhibited in TM Forum Smart City Submit, which can achieve hover monitoring, vertical taking-off and landing[12]. However, one limitation of fuel cells is their slow dynamic response that leads to voltage fluctuations even system instability when an abrupt power change is encountered. This is due to the complex dynamics associated with mass and heat balances of the stack[13].

III. Discussion

UAV fuel cells are electrochemical devices that convert chemical energy from fuels and oxidisers, without combustion, into useful electrical energy that can be used to power devices and vehicles. The cell itself does not require charging, but does require a steady flow of fuel and oxidiser. Hydrogen is the most common fuel, with oxygen from the air being the most common oxidiser. Multiple fuel cell technologies exist, including proton-exchange membrane (PEM), solid acid, and solid oxide. PEM is the most widely-used electrochemical cell used in UAVs as it has the highest power density. PEM cells also run at lower temperatures, making their construction and engineering less complex and costly, and giving them a lower thermal signature.

PEM fuel cells are based around a positive terminal and a negative terminal separated by a solid polymer membrane. The hydrogen fuel is fed to the negative terminal, where the hydrogen atoms are stripped of their electrons to become protons. The protons permeate through the membrane to the positive terminal. The electrons travel to the positive terminal via an external route, and this flow of current provides the useful electrical output of the cell. Oxygen from the air is fed to the positive terminal and combines with the protons and electrons from the hydrogen to form water. Because water is the only by-product of the process, they are highly favourable from an environmental and emissions standpoint.

Picture 1. Northwest UAV's PEM Hydrogen Fuel Cells



Hydrogen powered drones have a number of advantages over those powered by batteries and internal combustion engines. Drone fuel cells have a high energy density, meaning that they provide a greater energy output to mass ratio, which is particularly important for aviation and unmanned aerial vehicles. Hydrogen PEM fuel cells have provided up to three times the endurance at equivalent aircraft/payload weights compared to drone battery systems. In addition to having a relatively low energy density, batteries take a long time to recharge, with a charge cycle often being many times the typical half-hour flight endurance that they provide. Hydrogen cylinders can be swapped out within minutes, allowing for greater operational efficiency.

Fuel cell technology is quiet compared to internal combustion engines, the noise and vibration from which can affect the operation of UAV sensors and payloads. Internal combustion engines also require more maintenance and typically have a much lower MTBF (Mean Time Between Failures) than alternative fuels, requiring more spare parts and more manpower.

Hydrogen powered UAVs are more efficient at higher altitudes than many with internal combustion engines, which suffer more from derating due to the lower air density. Small internal combustion engines function at peak fuel efficiency only within a narrow band of conditions, and are also noisy and polluting with a high thermal signature.

[12] Cnbeta.com [Internet] A fuel cell vertical take-off and landing unmanned aerial vehicles unveiled at 2017 Smart City Summit. [updated 2017 Sep 27] [cited 2018 Mar 1]

[13] Kyung WS, Stefanopoulou AG. Coordination of converter and fuel cell controllers. Int J Energy Res 2005;29(12):563–8.

Hydrogen cells can be stacked in a modular fashion depending on the output voltage required. A complete hydrogen drone fuel cell power system will additionally incorporate control systems for fuel and air, as well as hydrogen regulators and liquid or air cooling systems. Although they feature a high energy density, hydrogen cells exhibit a relatively low power density, which translates to a low thrust to weight ratio for drones and other aircraft. This means that current electrochemical cells are not applicable to the largest UAVs, which require very high peak output power and thus are better served by traditional combustion engine technology.

Small-to-medium sized UAVs are thus the main current target market for PEM hydrogen fuel cell systems. Hybridized systems can also be fitted, these pair hydrogen cells with a small battery that provides extra power during high-demand phases of flight such as take-off, rapid climbing and high wind resistance, thus offsetting the aforementioned low power density disadvantage. The hybrid battery can be recharged during periods of low demand.

Designed for reliable operation even in extreme environments, drone fuel cell systems can enhance mission endurance and range, potentially enabling increased efficiency for BVLOS (beyond visual line of sight), ISR (intelligence, surveillance and reconnaissance) and long-range mapping and surveying UAS missions.

IV. Conclusion

Research analysis in recent years shows a development of fuel cells to proper means of transportation, such as: electric cars, ships and planes. The cost of hydrogen use is comparable to the price of petrol. A fuel cell would be approximately five times lighter than the current battery solution thus providing a similar range of flight. The difficulty in the latter case lies in low specific power drive units with fuel cells (specific power = power / weight power plant with fuel tank) and insufficient specific energy of the drive unit. Technological development of fuel cells progress in the field of material science has allowed for reducing the weight of a fuel cell unit by enabling the first practical attempt to use them in aerospace. A reason for the tests is the advantages of fuel cells in comparison with internal combustion engines in following applications: fuel cells operate silently by using particular predisposes in unmanned surveillance aircraft. They do not emit exhaust gases and have a low heat emission, which makes it virtually impossible to identify and destruct devices using infrared radiation, especially at night. Due to the lack of moving parts, vibrations are reduced, the maintenance is simplified, their reliability is increased and high efficiency of fuel cells is conserved. In relation to the competitive electric power from batteries, electrochemical fuel cell system weights more than 3.5 times less than the battery lithium-ion cells, 8 times less than the battery NiMh cells and 16 times less than the team of lead-acid batteries.

The feasibility to implement a fuel cell in a UAV could be asserted. From the study carried out in this work, the following conclusions can be drawn.

Fuel cell technology is still immature but improving, with clear room for improvement in weight, volume, and costs reductions. Compared with conventional systems, fuel cells offer higher energy density and lower specific power density.

Fuel cells offer potential advantages in low maneuverability UAVs, which are currently the most manufactured type (e.g., surveillance applications), and in high endurance operations.

PEM fuel cells have reached a more mature market. The facts of being of low temperature and having a fast start-up time are features consistent with the requirements of most UAVs. Reforming other fuels (e.g., natural gas, gasoline, etc.) remains an uninteresting option because the weight and volume of the reformer would need to be added. A jet fuel reformer could only be assessed in the case of large UAVs.

There are different fuel storage systems for each type of fuel cell. Therefore, in the case of a UAV, it is essential to minimize the weight of the overall propulsion system (fuel cell/storage system) without forgetting to consider the weight of auxiliary systems, such as thermal control or water management systems.

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